

Thorn, Major John C., M.C., Vancouver, British Columbia, Canada.

Trenor, Albert Delafield, Gloucester, Massachusetts, U.S.A.

Twomey, Patrick Victor O'Connor, Limerick, Ireland.

Varadachari, Perungavar, London.

Varma, Parsotamdas Govind Prasad, Lucknow, India.

Waddie, H. J., Ontario, Canada.

Watson, Arnott E., Lahore, India.

Watson, Charles Albert, Keighley, York.

Whitney, Willis Rodney, Ph.D., Schenectaday, New York, U.S.A.

Whitworth, John, A.R.C.A., Alexandria, Egypt.

Wilkie, Edward Thomas Irvine, Singapore, State Settlements.

The Chairman's address on "Exhibitions" will be published in the next number of the *Journal*.

PROCEEDINGS OF THE SOCIETY.

CANTOR LECTURES.

NITRATES AND AMMONIA FROM ATMOSPHERIC NITROGEN.

By E. KILBURN SCOTT, A.M.Inst.C.E.,
M.I.E.E.

LECTURE III.—*Delivered April 23rd, 1923.*

SYNTHESIS OF AMMONIA.

The synthesis of ammonia is the direct combustion of nitrogen and hydrogen, according to the equation $N_2 + 3H_2 = 2NH_3$. It is often called the Haber process, because its technical development was mainly due to Prof. Fritz Haber, but Regnault studied the problem in 1840; the French chemist, Le Chatelier, first pointed out the importance of working the synthesis at considerable pressure, and Prof. Nernst was the first to carry out experiments up to 75 atmospheres. Nernst used an iron catalyst, which was not as successful as he expected, but his work and that of Dr. Jost indicated technical possibilities.

In the meantime Prof. F. Haber had noted that good catalysing properties were possessed by such metals as uranium and osmium. With the assistance of Mr. R. Le Rossignol* researches were made up to

* Mr. R. Le Rossignol is a native of Jersey and therefore British. His work in making the synthetic ammonia process a success has not been generally recognised. He was a partner to the agreement when the rights were handed over to the Badische Anilin und Soda Fabrik in July, 1909.

200 atmospheres pressure, and they found that the ammonia equilibrium at that pressure and $600^\circ C$ was 6 per cent. Patents were taken out in their joint names.

A technical plant was constructed in 1909 which gave $\frac{1}{4}$ kilogramme of ammonia per hour and this was shown to Dr. Bosch, then manager of the Ludwigshaven Works, and to Dr. Mittasch, head of the research department of Badische Anilin und Soda Fabrik. As a result Dr. Mittasch wrote a favourable report and this and the enthusiasm of one of the directors, Von Brundt, caused the company to purchase the patent rights.

Large scale working brought forward difficult chemical and engineering problems, such as the manufacture of cheap hydrogen and the construction of large steel vessels to withstand the pressure. Drs. Bosch and Mittasch and engineers of the Badische and Krupp companies solved these. The first commercial plant of 25 tons a day started in 1913 is generally known by the name Haber-Bosch.

TECHNICAL PROBLEMS.

The commercial synthesis of ammonia is the most difficult chemical engineering problem that has yet been tackled, and its solution has opened up possibilities of endeavour in other directions, especially in the uses of catalysts and super pressures. The following were the most difficult points which had to be solved:—

(a) Cheap production of large amounts of pure hydrogen and pure nitrogen, especially the first named.

(b) The manufacture of steel vessels to withstand safely 200 atmospheres at a temperature approaching red heat in the case of the catalyst vessel.

(c) The use of a steel alloy very low in carbon so as to withstand the effects of occluded hydrogen and ammonia gases.

(d) The design of joints that would withstand the pressure and also vertical and lateral stresses set up by differential temperatures.

(e) A promoter to add to the pure iron or other main catalyser so as to increase the efficiency of the synthesis.

(f) Removal of the ammonia as formed in such a way as to conserve the pressure.

It was found that the structure of ordinary cast steel allowed the gases to pass through too easily and the carbons combined with the hydrogen to form methane, which

tended to cause blisters and other dangerous imperfections. It was also found that ammonia, at the temperatures of formation or decomposition had a powerful action on iron tending completely to break down its crystalline structure, probably by nitrification.

The difficulty was overcome by using very low carbon steel made in the electric furnace and alloying it with such metals as tungsten, nickel and chromium. The Badische Anilin und Soda Fabrik uses tungsten steel and M. G. Claude uses nickel chrome steel.

GERMAN FACTORIES.

The first factory was built at Oppau on the Rhine near Ludwigshaven and the second built during the war is at Leuna near Merseburg, Saxony. The Kaiser and his military party took great interest in the Oppau plant, especially when rumours of war began to increase.

It was foreseen that only by making explosives and fertilisers from atmospheric nitrogen could the Central Powers become independent of overseas supplies from Chili.

Before the war Germany was the largest market for Chili nitrate. To-day the country can not only make all that is required for home use, but could also export a considerable quantity if the exchange was anywhere near normal.

Towards the end of the war the Oppau factory employed 6,000 men and produced 220 tons of fixed nitrogen per day. The complete plant cost over £10,000,000, and a considerable proportion went in perfecting the process.

The Leuna factory was started in May, 1916, finished in eleven months, and by 1918 was producing 400 metric tons of ammonia per day. Since the war this plant has been doubled. Not much is known about its details, but being larger and built at a later date it is more efficient than the factory at Oppau.

The Leuna factory is associated with the ammonia soda process, and ammonia sulphate is made.

DESCRIPTION OF OPPAU PLANT.

The following description is taken from accounts written by those who were authorised by the Treaty of Versailles to inspect the plant, the best published report being that of Lieut. McConnell, of the

Nitrate Division of Ordnance of the U.S. Government.*

There are 15 catalyser units, each capable of producing 20 tons of ammonia per day, but as they do not all run at the same time, the maximum output is about 250 tons a day.

Each unit takes about $12\frac{1}{2}$ million cub. ft. of nitrogen and hydrogen per day and about 6 per cent. is formed into ammonia, which, with the uncombined gases is then passed through absorbers and the ammonia is extracted by means of water.

About 10 per cent. of the gas is lost, as the argon and methane are allowed to accumulate to several per cent. and then the amount is reduced by blowing off.

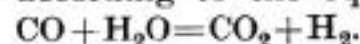
Each catalyst bomb with its heat inter-changer and absorber is placed in a bomb-proof compartment built of brick which has iron doors lined with strong planking.

HYDROGEN BY CATALYTIC ACTION.

When the Badische Anilin und Soda Fabrik began to develop the Haber process on a commercial scale it was seen that a principal factor was an ample and cheap supply of hydrogen. About 70 per cent. of the total cost of making synthetic ammonia goes in the preparation and purification of the hydrogen gas. After various experiments Drs. Bosch and Mittasch developed the following method.

The producers are like those for making commercial water gas and give a mixture of about 50 per cent. of hydrogen and 40 per cent. of carbon monoxide. There are 12 of the Pintsch type each measuring 15ft. by 25ft. Ruhr coke is used at the rate of 30 tons per day in each, and about three million cub. ft. are produced.

Further, hydrogen is also made with the help of the carbon monoxide by causing it to react with steam in the presence of a catalyst according to the equations—



There are 26 catalyser units, each having two heat exchangers and one catalyst chamber 16ft. by 12 ft. by 10ft., and each chamber has two beds of catalyser material, consisting of oxide of iron and a promoter.

The process requires much heat and the use of a very large excess of steam, so it is distinctly expensive. The next step is for removal of the carbon dioxide; the

* See article in *Industrial and Engineering Chemistry* for September, 1918.

gases are first cooled, then compressed to a pressure of 25 atmospheres, and finally put through water scrubbers which remove most of the carbon dioxide and also about 10 per cent. of the hydrogen.

The water enters the top of eight steel towers packed with rings, each 4ft. diameter and 30ft. high, and gas enters at the bottom at slightly lower pressure. The water washes out the carbon dioxide and as it issues it drives Pelton wheels which regenerate about 60 per cent. of the power.

The small amount of monoxide which remains in the hydrogen gas is removed by eight steel towers, 2½ft. diameter and 30ft. high packed with hollow balls. The gas enters at 200 atmospheres pressure and the carbon monoxide is absorbed by ammoniacal copper formate solution. Afterwards the monoxide is drawn from the copper solution by pumping it through two steel towers. The copper solution is then used over and over again.

There are also eight additional steel towers similar to the above, through which sodium hydroxide solution is pumped for further purification of the hydrogen. The nitrogen is made by a Linde liquid air plant, similar to that illustrated in the second lecture. Gas is added to the purified hydrogen to the extent of 25 per cent.

ELECTRIC POWER.

A very considerable amount of electric power is required for operating the various parts of the plant, such as compressors for raising pressure of gases to 200 atmospheres and for circulating the gases; pumps for circulating water at 200 atmospheres for absorption of ammonia, also for circulating copper formate solution and many other purposes.

This power is generated from lignite, each Kg. of which gives three cub. metres of gas containing 29 per cent. of CO and 12 per cent. of H. The gas is made in producers of the type B.A.M.A.G., which means Berlin Anhaltischer Maschinenbau Aktien-Gesellschaft. Each producer measures 12ft. by 25ft., and it burns lignite briquettes 2in. by 4in. at the rate of 20 tons per day, which gives two million cub. ft. of gas per day, representing about 18,000 kilowatts.

When suggestions are made for carrying on industries in this country which require large amounts of electric power, one is often met by the remark that we cannot

do as Germany and America because we have no water power, the implication being that nearly all modern industries abroad are carried on with water power. As a matter of fact, that is not so. The industries of Germany that we are now discussing are carried on with electric power generated from poor fuel, mostly lignite coal.

The largest electric power station in Europe at the present time, 185,000 k.w., was built at Bitterfeld in Germany during the war, mainly to supply energy for fixation of atmospheric nitrogen. It uses a poor quality lignite that our industrialists would sniff at. The manufacture of hydrogen gas alone at the synthetic ammonia plant at Merseburg takes 40,000 horse power, and the arc process plant built there during the war took 60,000 kilowatts all generated from lignite.

HABER BOSCH CATALYST BOMB.

The bomb or vessel used at the Oppau factory is shown in Fig. 19. It consists of two forgings made by the Krupp firm of tungsten steel, containing very low carbon. Each is 19ft. 7in. long, 3ft. 9in. outside diameter and the wall is about 7 inches thick.

The end covers, 2ft. thick, are fastened down by 15 tap bolts, each 4in. diameter and the flanges of the two halves of the vessel are also held in the same way. The total weight is 74½ tons.

The vessel is lined with electrolytic iron, and the hydrogen gas passes through the lining, and is allowed to escape by numerous small holes, which are drilled through the steel.

Inside the iron lining there is a layer of refractory material, which is held by another liner, the rest of the space, about 20 inches diameter, being occupied by catalyst material. This consists of pure iron and a promoter.

The outside of the bomb is heavily lagged so as to conserve heat and keep the catalyst material at about 600° C. Electric heat is used for starting and about three days are required to get everything warmed up ready for work.

HEAT INTERCHANGERS AND ABSORBERS.

Each catalyst bomb has its own heat interchanger, which is of similar construction and of tungsten steel forgings, 19ft. 7in. diameter and 15in. inside diameter.

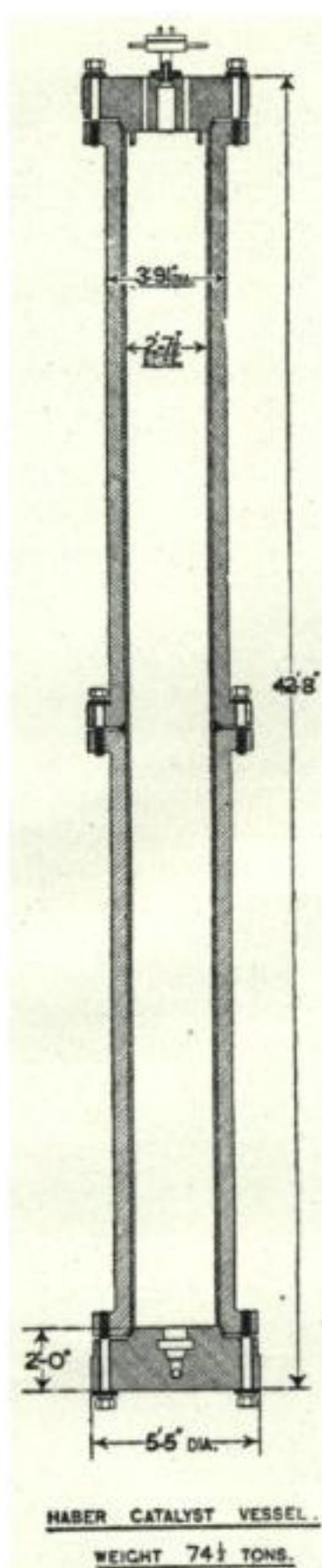


FIG. 19.—Cross section of Haber-Bosch Catalyst Bomb.

It is made of tungsten steel with a liner of pure iron and weighs $74\frac{1}{2}$ tons. The contained catalyser material will deal with 20 tons of ammonia per day of 24 hours.

The inside is filled with $\frac{1}{8}$ in. diameter steel tubes welded into steel plates at the ends.

Each catalyst bomb has also its own absorber for removing the ammonia with water under a pressure of 200 atmospheres. Each absorber has three sets of spiral steel

coils one above the other, the upper being at a height of 60ft. They are water cooled.

The gases pass down the lowest spiral and then through the others in succession, whilst the absorbing water flows from top to bottom by gravity and scrubs out the ammonia as a 20 per cent. solution.

The uncombined gases then pass forward to the catalyst bomb again and have thus to be kept in continuous circulation at 200 atmospheres pressure. It is costly and complicated when compared with the Claude process, which will be described later.

POST-WAR DEVELOPMENTS.

After the war, various concerns interested in the manufacture and sale of compounds made from atmospheric nitrogen formed an association called the Stickstoff Syndikat G.m.b.H., which is a long way of writing Nitrogen Syndicate.

The capital stock is held by the Badische Company, which makes synthetic ammonia, the industrial companies who manufacture cyanamid, the German Ammonia Sales Co., and affiliated organisations of the coke works and gas works. The board of directors includes representatives of the Government.

Prof. Caro represents the cyanamide producers; Dr. Bueb represents the Badische Anilin und Soda Fabrik; and Geheirath Bruckner represents the coke ovens concerns.

The most reliable information regarding the output of Germany in 1920 was given in a speech which Prof. F. Haber delivered at Christiania in that year, when he received the Nobel Prize. He said:

People think that the Norwegian industry may be hurt by my method of making synthetic ammonia. I do not believe it. The world's demand for nitrogen is so extremely great that it can be satisfied only by an intimate co-operation of the different methods. It is impossible that in the near future there will be an over-production of nitrogen, but I do believe the cyanamid industry will come on difficult times. Cyanamid is made from carbide, which has multifarious uses, and now is more used for making other things than cyanamid. As an example I would mention its importance for automobiles. I think its use for that will be because there are not very great quantities of benzene and benzol in the world. Germany is now producing enough fixed nitrogen for its own use and does not need any imports. The German nitrogen production is at the moment a little insecure, as we have not yet the necessary working quietness. But if no political obstacles arise, we shall by my process produce 150,000 tons (metric) of fixed nitrogen this year. Add to that 100,000

tons of nitrogen from coal, and 100,000 tons of nitrogen from cyanamid, and that gives a total of 350,000 tons of fixed nitrogen for the year, which is more than Germany used before the war.

EXPLOSION AT OPPAU FACTORY.

On September 21st, 1921, an explosion occurred which killed over 6,000 people and destroyed part of the factory. The destruction has been attributed to a stock of 4,500 tons of mixed nitrate and sulphate ammonia which had set hard and was being blasted at the time. This material did disappear, but there were two explosions and the true explanation of what really happened will probably never be known.

A Parliamentary Committee of Enquiry was set up to find answers if possible to the following questions:—

(1) Is there any evidence of a criminal act? (2) Was an exceptionally powerful explosive used, and could it have been the cause of the explosion? (3) Could the use of a large amount of the explosive normally employed have caused the explosion? (4) Can a normal fertiliser-salt be exploded with the explosive used? (5) Can a salt of abnormal composition be exploded? (6) Could such an abnormal salt have been present? (7) Can a positive answer be given as to the origin of the explosion? (8) Does the fact that two successive explosions occurred indicate the possibility of another cause, and can that fact be harmonised with the suggested explanation?

Recently Prof. Wohler has reported that experts gave negative answers to nearly all the questions, including No. 7. They also found that the charge of negligence against the *Badische Anilin-und-Soda-Fabrik* could not be sustained, as even when every possibility was taken into consideration, such an explosion as occurred could not have been foreseen. The experts recommend that blasting of fertiliser salts containing nitrate be forbidden.

It is probable that the first explosion acted as a detonator to the second, and the first may have been caused by an accidental mixture of hydrogen and air. It can hardly have been caused by the bursting of a catalyst bomb or other vessel due to failure of the steel.

AMERICAN PLANTS.

During the war a modified Haber process plant was designed by the American

Chemical Co., and erected at Sheffield, Alabama, where it was called Nitrate Plant No. 1. The flow sheet is shown in Fig. 20. It was not a success because there was not enough knowledge available.

The pressure used was 100 atmospheres, and hydrogen was made from water gas by the catalytic method. When the question of ownership of the Mussels Shoals plant is decided Nitrate Plant I. will, no doubt, be redesigned.

Since the war a Haber plant has been built at Syracuse, New York, to make 10 tons of synthetic ammonia per day. It is worked in conjunction with a Solvay process plant.

SYNTHETIC AMMONIA AND NITRATES CO., LTD.

In 1918 the British Government did some preparatory work towards establishing a factory at Billingham-on-Tees to make synthetic ammonia on a modification of the Haber process as worked out by Dr. H. Greenwood at University College, London.

After the Armistice it was decided to hand over the completion of the plant and all test records, drawings and patents rights, etc., to a company having the above title to be formed by Brunner Mond and Co., Ltd. All the information and patents of Dr. Maxted and Gas Developments, Ltd., were also purchased.

The company is always to be British controlled and the directors British born, and in case of war it is to be turned over to the Government for production of explosives material, etc.

To gain information of actual running of the process preparatory to large scale working, a small commercial scale unit has been working for some time at Runcorn, in Cheshire. The ammonia is sold as strong liquor.

The works at Billingham-on-Tees are approaching completion, and are expected to turn out 120 tons of ammonia sulphate and ammonia chloride per day. The site is on the bank of the Tees and included 850 acres, and a river frontage of a quarter of a mile. It is proposed to build wharves capable of accommodating the company's own large cargo steamers, and to extend the plant to a production of 1,000 tons per day.

The company has spent about £100,000 on a fine research laboratory.

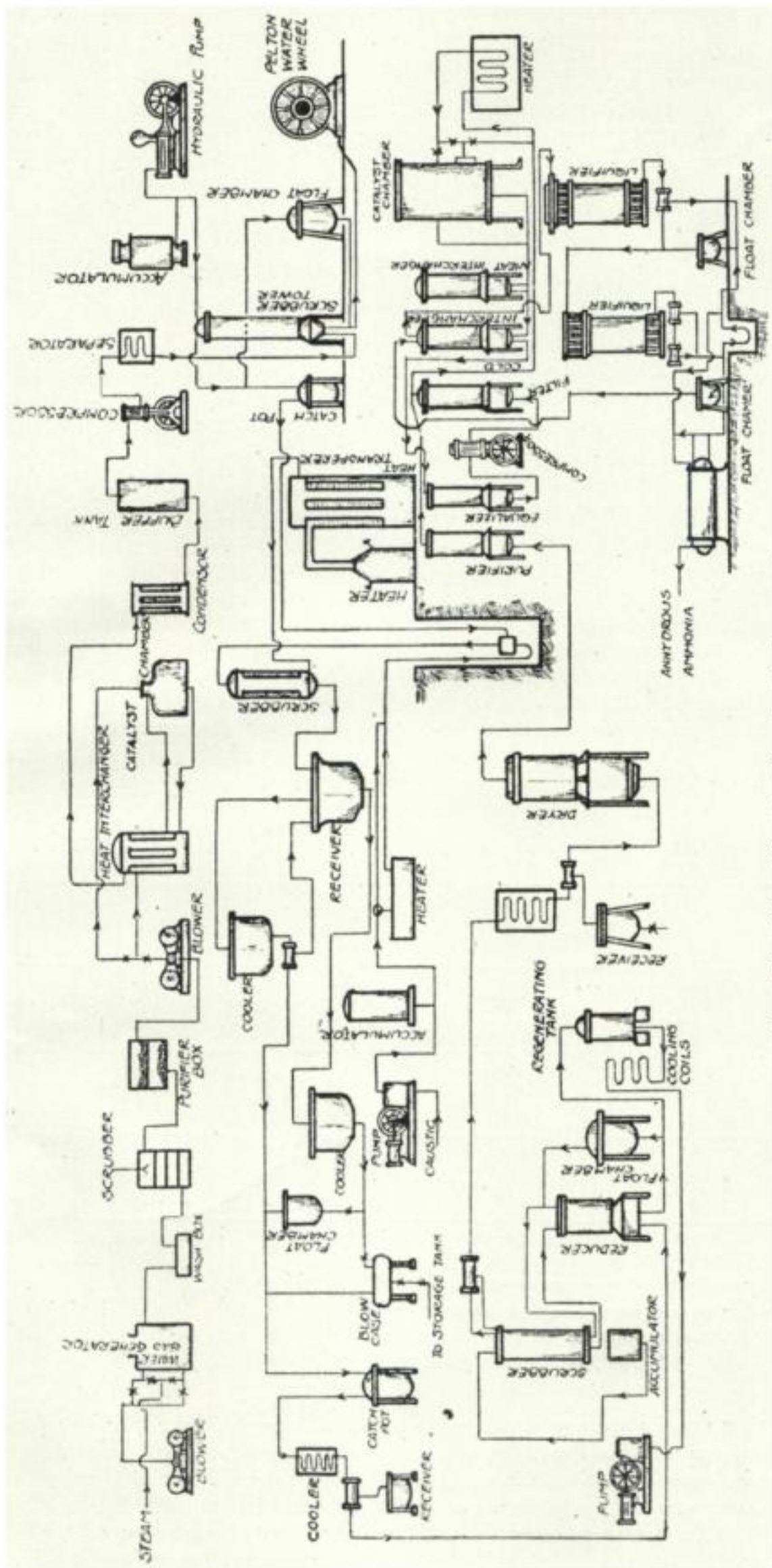


FIG. 20.—Flow Sheet of Synthetic Ammonia.
Flow sheet of synthetic ammonia, American modification by the Haber process at Nitrate Plant No. 1, Sheffield, Ala.

CLAUDE PROCESS.

The name of M. Georges Claude had been known for many years in connection with his liquid air process, when in 1917 he worked on the synthesis of ammonia at much higher pressures than those tried by Naber and Le Rossignol. In this connection it may be mentioned that French engineers have always been to the fore in using high pressure.

In 1882-5 Mekarski used air at 45 and then 80 atmospheres to work street tramcars in Paris, and in 1890 the compressed gas industry began to use 150 atmospheres. In the 30 years from 1890 the limit of pressure was only advanced 33 per cent., and then M. Georges Claude, with typical Gallic audacity, advanced it by over 400 per cent. It was brilliant and it was successful, for he proved that it is possible to construct chemical engineering apparatus satisfactorily to resist 900 atmospheres.

He was partly led to the employment of this very high pressure by knowing that energy required to compress gas increases with the logarithm of the pressure, and thus the expenditure of energy only increases from 2.3 to 3, when the pressure is carried from 200 to 1,000 atmospheres, as shown by the flattened curve of Fig. 21.

PERCENTAGE EQUILIBRIUM OF AMMONIA.

Before M. G. Claude used 900 atmospheres Prof. Le Chatelier had expressed the opinion that at very high pressure the reaction of nitrogen and hydrogen might be spontaneous, but it was found that a catalyst was still required, although it could, of course, be relatively much smaller than for 200 atmospheres. Claude also found that the useful temperatures of reaction were about the same, namely, between 500 and 700° C.

The most important fact discovered was that the equilibrium percentage of ammonia at 900 atmospheres was much better than was expected by extrapolation from the experimental results of Haber and Le Rossignol.

The curves in Fig. 22 are based on Claude's experiments and it will be seen that results due to great pressures are almost proportional and that with the Haber pressure of 200 atmospheres the percentage of ammonia is 13 per cent., whereas with 1,000 atmospheres, it is 40 per cent.

In actual practice the figures are about 6 per cent. and 25 per cent., but the Claude process recovers 28 per cent. because of the refrigeration by evaporation of the liquid ammonia. I am informed that it amounts

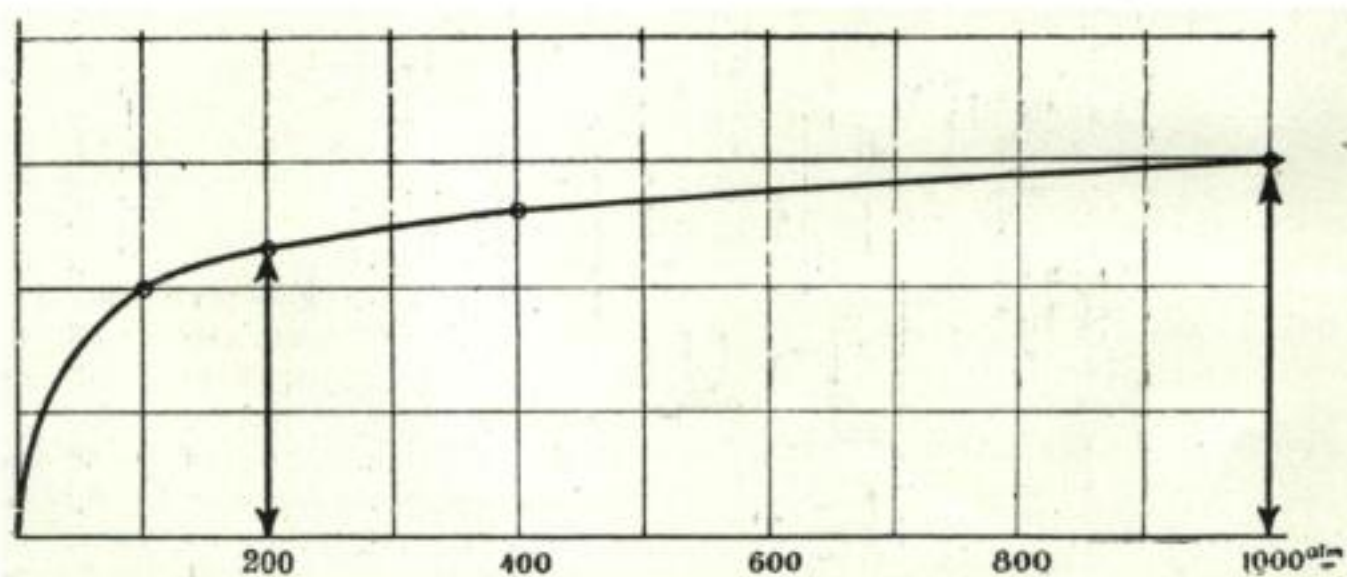


FIG. 21.—Work and Pressure.

This shows how the work of compression increases with pressure, and it will be noticed that the height of the curve for 900 atmospheres, as used by Claude, is not very much higher than for the 200 atmospheres as used by Haber.

The engineering details were worked out by engineers and metallurgists with whom M. Claude is associated, and it is of interest to note that experience in the design and construction of artillery was of very great assistance.

to one horse power per hour per 2,500 frigories of cold.

In several commercial plants Claude has demonstrated that with 100 cub. metres of gas per litre of capacity of the catalyser, and per hour he can get 5 kilograms of

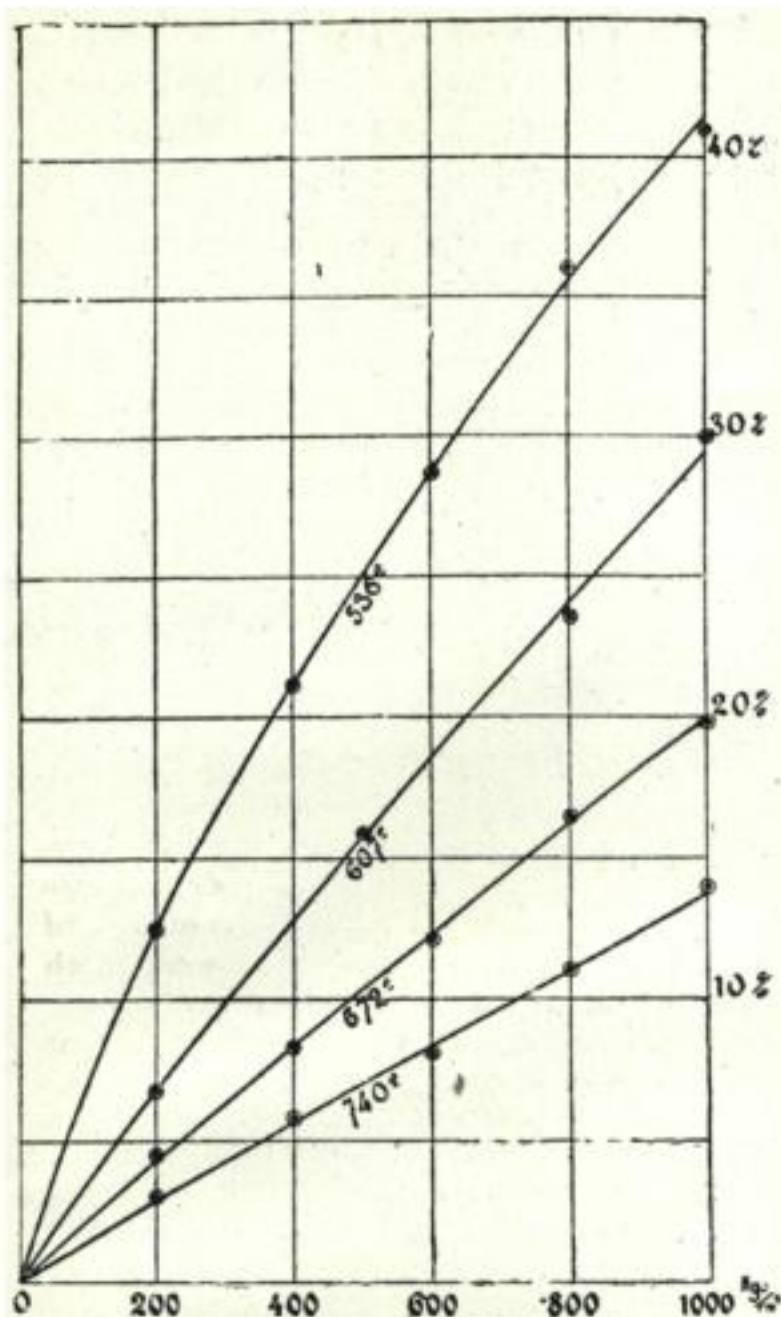


FIG. 22.—Ammonia Equilibrium.

These curves show that the ammonia equilibrium increases rapidly with rise of pressure, and also that the lower the temperature the higher the combination. Claude works at 900 atmospheres and 600° C., and it will be seen this gives an equilibrium of about 28 per cent. The Haber figure is much lower because the pressure is only 200 atmospheres.

ammonia per kilogram of catalyser material instead of 0.5 as obtained by Haber.

ARRANGEMENT OF CLAUDE PLANT.

Fig. 23 shows the layout of the Claude plant as installed at Montereau and at Béthune in France and also Barcelona in Spain.

The hydrogen and nitrogen pass from gasholders A and B through meters CC, where they are mixed in correct proportions by valve D. The mixed gases then pass to compressor E and super-compressor F, by which the pressure is raised to 900 atmospheres. Oil and water are removed by separator G, and the gases then pass

through a tube about the size of a man's thumb, to heat interchanger H and protection tube J. This tube removes any traces of carbon monoxide, and oxygen and any water and methane formed is condensed by cooler M, and removed by separator K.

The pure gases now pass through heat interchangers H_2 and H_3 and the first two catalyst tubes L_1 and L_2 , which it will be noticed are in parallel. They return via cooler M_2 to the separator N_1 , where the liquid ammonia formed is withdrawn. The uncombined gas then continues through heat interchanger H_4 to the third catalyst tube, L_3 , back through cooler M_3 to separator N_2 , where more ammonia is withdrawn. Finally all the remaining gas goes to the catalyst tube L_4 and back to separator N_3 , where more ammonia is removed.

The ammonia collected by the separators N_1 , N_2 and N_3 is then blown into the collecting bottle O, and from there to the storage cylinder P.

HYDROGEN AND NITROGEN.

The method used by Claude for separating hydrogen from carbon monoxide in water gas by means of great cold is shown in Fig. 24. The carbon monoxide and hydrogen gases enter the tubular system by the pipe marked CO and H and pass to the lower ends of the tubes, which are in a bath of carbon monoxide boiling at minus 190°C.

By the action of this bath a large part of the ascending carbon monoxide is liquefied and it falls back into the bottom and passes by a small pipe to a spray which is above the bath and this gradually replaces that which is evaporated.

The remaining gases continue to rise in the tubes and meet with a still lower temperature, which has the effect of liquefying the rest of the carbon monoxide.

Hydrogen leaves the top of the apparatus and enters a small engine in which it expands and is further cooled by so doing. It then passes round the upper ends of the tubes when it produces the very low temperature above mentioned, and finally passes out.

At the Claude plant at Montereau the nitrogen is obtained by burning oxygen out of air. The method is remarkably simple and where there is plenty of hydrogen available it is the best way to get nitrogen as the gas is pure.

Nitrogen can be obtained from the exhaust of the carbon monoxide gas engine, and, of course, it is a bye-product of the manufacture of hydrogen from water gas.

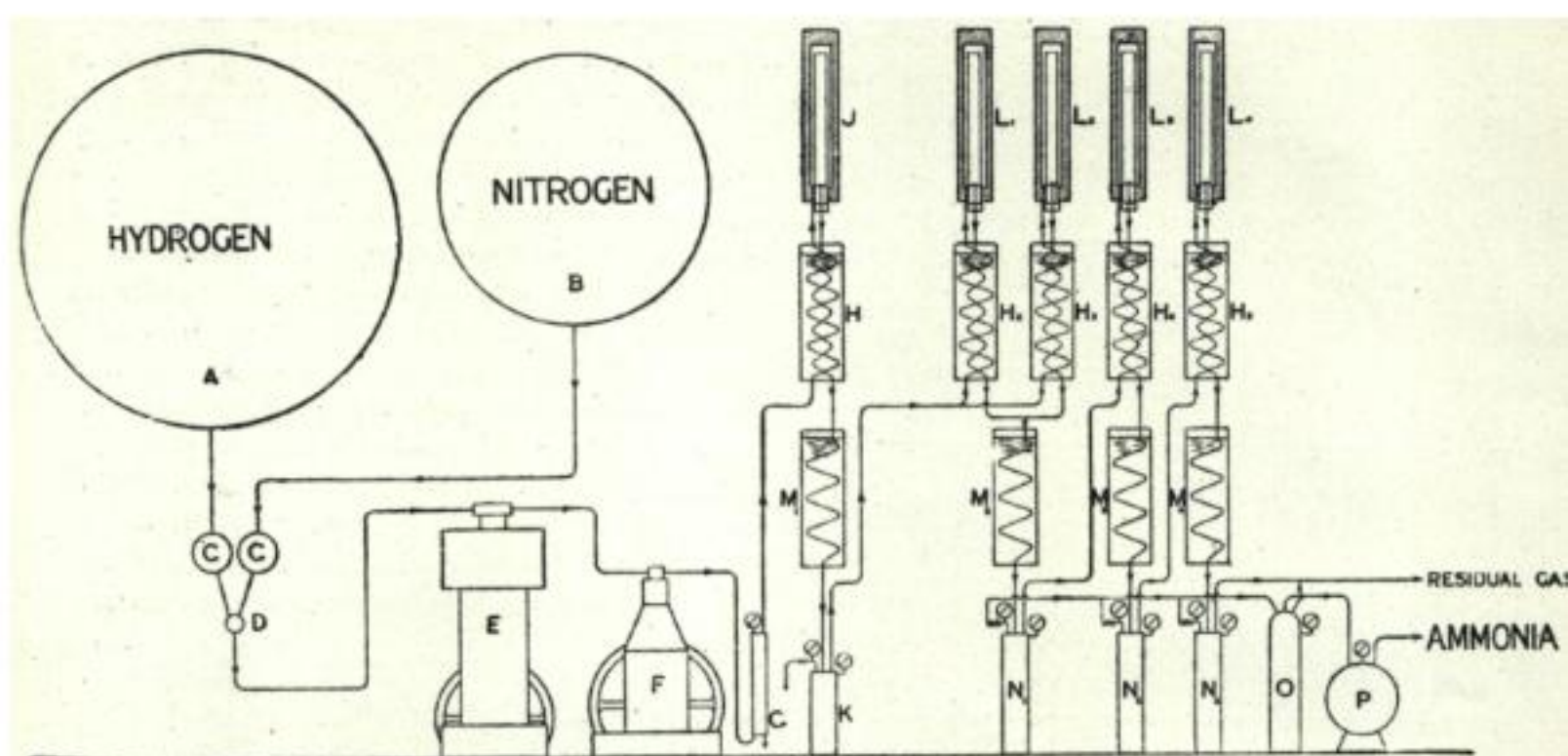


FIG. 23.—Layout of Claude Synthetic Ammonia Plant.

A and B are gas holders, C C the meters, and D is a mixing valve; E is the compressor. F the supercompressor and G a separator of oil and water; H is a heat exchanger; J the protector tube to remove traces of carbon monoxide and oxygen, M_1 a cooler and K separator of water: H_2 , H_3 are heat interchangers in parallel, L_1 and L_1 catalyst tubes in parallel, M_2 a heat interchanger and N_1 the separator of liquid ammonia: H_4 and H_5 , L_3 and L_4 ; and M_3 and M_4 and N_3 and N_3 are heat interchangers, catalyst tubes, coolers and ammonia separators in series connection, G is the collecting bottle and P the ammonia storage cylinder.

SUPER COMPRESSION.

The first plant installed at Montereau was for making two tons of ammonia per day with hydrogen from water gas. It had two compressors, the second or super-compressor being of the vertical type with two stages. In the later plant to make five tons per day all the eight stages are combined in one horizontal slow running machine, five stages being on one rod, three on the other rod giving 300, 450 and 900 atmospheres.

The details of design are very clever; and it may be mentioned that the tightness of the glands is secured by means of rings of compressed leather. I was told that they act better as the pressure increases.

This compressor passes 700 cub. metres of gas per hour, and it is driven by ropes from a 300 horse-power engine which works with carbon monoxide gas, which gas is obtained from the water gas plant after the hydrogen has been removed.

The pipes for carrying the gases are relatively very small, for example, a pipe to carry 700 cub. metres of gas per hour sufficient for a 5-ton plant is only the size of a man's thumb.

The tightness of joints depends much more upon dimensions than upon pressure, and

the gaseous volume is reduced to such an extent with 900 atmospheres, that the joint is easier to keep tight than one at 100 atmospheres.

PLANT AT COKE OVENS.

At Béthune in Northern France a Claude plant is worked with hydrogen from coke oven gas which gives 5 tons of ammonia per day. Extensions are being carried out to raise the output to 20 tons per day.

Coke oven gas is more difficult to deal with than water gas, because of the presence of constituents which vary widely in character. The gas at the Béthune coke ovens gives 49 per cent. of hydrogen instead of the usual 54 per cent., and, therefore, 850 cub. metres per hour is treated to give 425 cub. metres, 90 per cent. of which is hydrogen, 1.6 per cent. is carbon monoxide and the rest nitrogen.

The gases from the exit of the benzol extractors are compressed to 25 atmospheres and conveyed into a first column to be freed from remaining benzol by a current of heavy oil circulated by a small pump.

They then pass to a tower in which water dissolves most of the carbon dioxide, the last traces being removed by lime-water injected at the top of the tower. It is

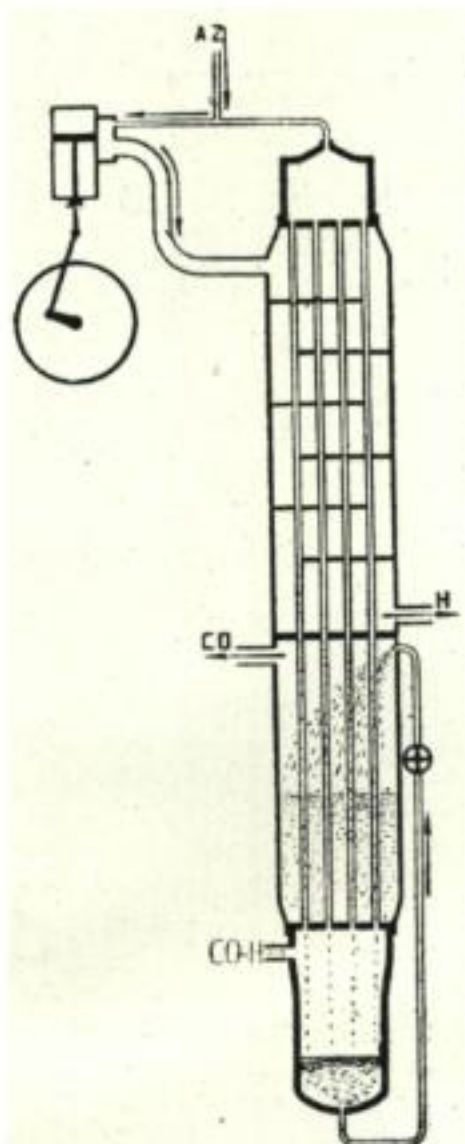


FIG. 24.

The carbon monoxide and hydrogen enter by pipe marked CO and H, and pass to the lower ends of the tubes, where there is a bath of carbon monoxide boiling at 190°C . The hydrogen passes out by the pipe marked H and enters the small engine, in which it expands and is further cooled and it then passes round the upper end of the tubes and produces very low temperature.

important to remove all the carbon dioxide as otherwise it would solidify and choke up the liquefaction apparatus.

The compressed gas is progressively cooled and the ethylene and similar hydrocarbons liquefy out, then the methane, then the carbon monoxide, and finally the nitrogen, leaving only the hydrogen in the gaseous state. The nitrogen is liquefied at the top of the apparatus and in running down it washes away the last traces of carbon monoxide.

The hydrogen is allowed to expand whilst doing external work in an engine, and it is thereby cooled to minus 215°C ., and subsequently absorbs heat from the incoming coke-oven gas in a heat interchanger. The lubrication of the engine is done by adding a little nitrogen which

liquefies in the cylinder. The cost of hydrogen separated in this way is said to be 1s. 6d. per 1,000 cub. ft.

The hydrogen is conveyed to a gas holder and the other gases which are rich in methane are returned to the works to be utilised. They represent a calorific power of 6,000 calories per cubic metre, and two-thirds of the initial calorific power is thus returned to the coke works. The entire removal of benzol under pressure increases the yield of benzol from 10 to 15 per cent., and the ethylene gives 200 kilograms of alcohol per ton of ammonia product. These pay for the cost of compressing all the gases.

CLAUDE CATALYSER BOMB.

The standard catalyser bomb is 7ft. high, 9in. outside and 4in. inside diameter. It is made of special nickel chrome steel having very low carbon so as to resist occluded hydrogen. It is cast solid, machined and tested for flaws.

Some of the first bombs were made by Vickers, Ltd., of Sheffield, of a special alloy called "Vikro." Mr. Dickenson* head of their research department, has shown that neither Vikro nor any other steel has true tensile strength above a low red heat. The essential property in resisting deformation under stress is the equivalent of viscosity in a fluid. The special advantage of nickel chromium steel is that it has greater resistance to deformation at high temperatures, the rate of flow being a practically negligible amount at a stress of $8\frac{1}{2}$ tons per sq. inch at 500°C .

The head of the bomb is fixed by an interrupted thread like that of the breech mechanism of a gun, and enables the catalyst to be either put in or taken out in eight minutes. The joint is made by a thin copper washer, and the screwing up is done by means of a wormwheel attached to the head, rotated by two worms geared to a crank. When the catalyst has to be changed, rotation of the moveable head by a quarter of a revolution is sufficient.

Cold gases enter at the bottom end of the tube, which assists materially towards keeping the joint tight and as these gases cool the steel it is the better able to withstand pressure.

* See "Flow of Steels at Low Red Heat," read at the autumn meeting of the Iron and Steel Institute, 1922

It has been found that when a catalyser tube does burst the outer layer of metal gives way first, due to transmission of intense heat towards the exterior causing a great fall of temperature. The internal hot layers of metal thus exert great pressure on the exterior layers. As a means of reducing this difference in temperature the outside of the bomb is lagged.

CATALYSER MATERIAL.

Many substances will give good activity for a short time if pure gases are used, but the practical ideal is to use a catalyst material which will give a long active life under works conditions and with gases which are not technically pure.

Claude catalyser material is made by burning iron in oxygen gas, this oxide being afterwards reduced by the hydrogen of the process. A promoter is also added to increase activity of the synthesis to give immunity from poisons. The material is granular, shiny black in colour and is easy to make and to keep.

As will be seen from Fig. 25 it is packed into an inner tube made of sheet iron and then is covered with a non-conductor of varying thickness. The gases enter cold at A and as they pass upwards to B they take up heat from the reaction from the catalysing material. By the time the gases arrive at the top of the inner tube and pass into the catalyser material they are at about the right temperature, namely, 500° C.

The flood of heat from the reaction is sufficient to give about 60,000 calories per hour. When first starting up from cold the catalyser tube is heated up electrically.

PROTECTOR TUBE.

A plant to make five metric tons of ammonia per day requires four such catalyser bombs. Each bomb weighs 15 cwts., so that for an output of 20 metric tons there would be 16 bombs, which weigh about 12 tons as against the 74½ tons required for a single Haber Bosch bomb for the same output.

A Claude plant has in addition, a protector tube for the purpose of removing any carbon monoxide that may be still left in the hydrogen gas.

This gas is one of the most deadly poisons of catalyser material, and it is very liable to be present in hydrogen made from coke oven gas. With the Claude process as

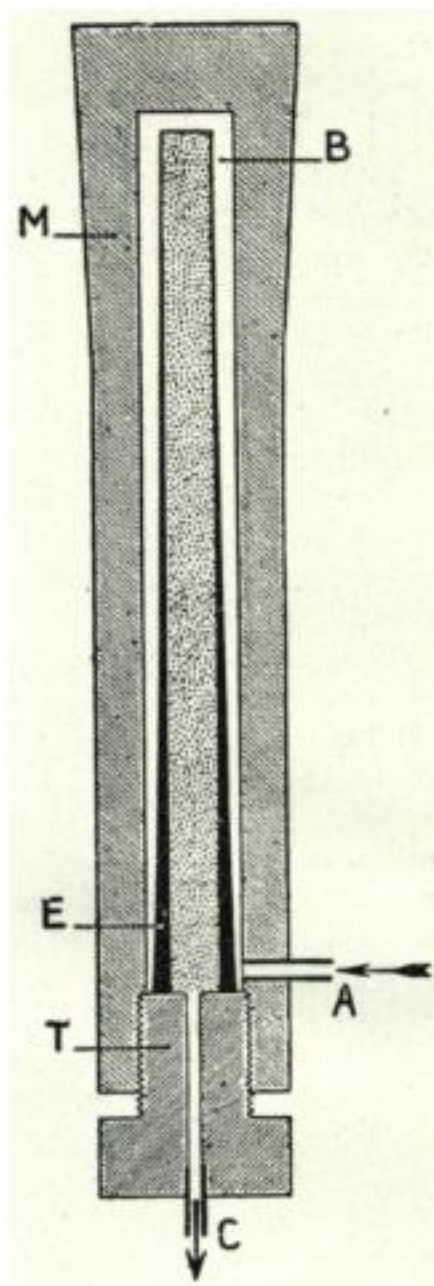
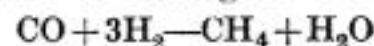


FIG. 25.—Claude Catalyst Bomb.

Made of nickel chrome steel with very low carbon. The movable end has an interrupted screw thread like that of a breech mechanism. It carries a tube filled with catalyst material, which is pure iron with a promoter. The mixed nitrogen and hydrogen gases enter cold, and in passing upwards attain a temperature of about 2,500° C. before passing downwards through the catalyst material.

much as 3 per cent. may still be present before it is finally removed by this protector tube.

It is similar to the catalyser bomb, except that its inner tube is filled with spent catalyst material. This is heated electrically to 400° C. and the carbon monoxide which passes through is converted into methane according to the equation:



At the same time any oxygen that may be present is burned to water.

All the five tubes are arranged vertically in a housing made of reinforced concrete, which is above ground. There are no special precautions to keep visitors away.

REMOVAL OF AMMONIA.

By using 900 atmospheres it is easy to remove the ammonia because the cooling down of gases by means of coils immersed in water is sufficient to liquefy over 95 per cent. of the ammonia. The remaining ammonia can be removed from the gases by further cooling produced by the vaporisation of part of the ammonia, or by absorption in sulphuric acid. After removal of all the ammonia the uncombined or residual gases return to the system.

It will thus be seen that the procedure is a very simple procedure compared with the Haber system at 200 atmospheres, in which it is necessary to inject water into the system and recover the ammonia as an aqueous solution. This consumes a good deal of power and involves complication of plant, also if the ammonia is required in the anhydrous state the liquor has to be treated.

There is a steady sale at good prices for liquid ammonia for refrigeration, etc., and it is convenient to make it in small lots at a number of centres, and so cut down cost of carriage.

I believe that some day large industrial districts will have synthetic ammonia plant and synthetic nitrate plants for there is a great future in the development of synthetic processes.

COST FIGURES.

The following figures, due to Mr. J. H. West,* give the power required per ton of ammonia made with hydrogen from coke oven gas by Claude process :—

		K.W. hr.	Per cent. of total.
Nitrogen	279	8.53	
Hydrogen	1,287	39.35	
Compression ..	1,530	46.78	
Miscellaneous ..	175	5.34	
Total	3,271	100.00	

* "Claude Synthetic Ammonia Process and Plant," by J. H. West, *Journal of the Society of Chemical Industry*, November 30th, 1921, Vol. XL., No. 22, pp. 420 R-424 R.

With steam power at 6d. per unit, the total cost is £6 16s. 3d. If the hydrogen were obtained by electrolysis, then 13,590 units would be required, making with the other amount a total of 15,574. At 1/10d. per unit this is about £6 10s.

As a matter of fact, hydrogen is a by-product of several electrolytic processes, and the tendency in future will be to use it at these several plants for making synthetic ammonia. I believe that there will be considerable development in U.S.A. in this direction.

WEST-JAQUES HYDROGEN PROCESS.

A Claude plant to make five tons of ammonia per day is being built in Japan, and a contract has been entered into to extend it to 40 tons a day within two years. As local coke is very poor the hydrogen is going to be made by the West-Jaques process of which the following is a description.

This process combines the distillation of coal in a retort and the formation of water-gas from the resulting coke, also the conversion of the carbon monoxide from these operations into carbon dioxide and hydrogen. This is done by reaction with steam in the presence of a catalyst and in one apparatus. The process has the advantage of avoiding the heat and carbon losses incurred by withdrawing hot coke from retorts into the air and quenching with water.

The hydrogen in the crude coal is practically all liberated by passing the crude coal gas through a hot zone in the producer, so that all tar oils and hydrocarbons are cracked or split up into hydrogen and carbon, the carbon reacting with steam to form water gas. It is carried out in a modified form of Tully complete gasification plant, and the only products are gas and ashes.

Mr. J. H. West has had exceptional opportunities of investigating the Claude process, and it may, therefore, be of interest to quote the following opinion :—

"I am thoroughly convinced that the Claude process in points of low capital costs, simplicity, and absence of snags is far superior to the Haber."

Much the same conclusion has also been expressed publicly by Mr. H. S. Weeks, F.I.C., head of the chemical research department of Vickers, Ltd.

ELECTROLYTIC HYDROGEN.

At Terni in Italy Dr. Casale has a synthetic ammonia plant in operation which uses a pressure of 500 atmospheres.

The hydrogen is obtained by electrolysis, and it is of interest to note that when made in that way it is very pure, so that the expense of purification apparatus is saved. The oxygen is also pure and the final cost of the hydrogen depends on whether there is a ready sale for the oxygen.

The two kinds of cells used for electrolysis are known as the Filter press type and the Tank type, and the electrolyte may be sulphuric acid or caustic soda. The latter is generally used and it requires 1.69 volts per cell.

Theoretically considered one ampere for one hour should cause the evolution of .0147 cub. ft. of hydrogen measured at normal temperature and pressure, but in actual practice 1,356,170 units of electricity are required for 1,000 cub. ft. of hydrogen and 500 cub. ft. of oxygen.

At £5 per kw. year and on a power consumption of 135 kw.h. per thousand cub. ft. of hydrogen the cost of power is about 1s. 7d. per thousand cub. ft. of hydrogen.

Dr. E. B. Maxted has stated that if a certain plant takes 10,000 kw. of electric energy, then if the hydrogen is made electrolytically, about 7,500 kw. would be required for that purpose. Also he states that about 1,000kw. would be used for making liquid air to produce nitrogen

HABER.

Number of operations.

A chain of operations at 200 atmospheres, which pressure has to be restored at each step.

Condensation of Ammonia.

Water has to be injected at 200 atmospheres to wash out the ammonia, as a 20 per cent. solution. If liquid ammonia is required it has to be specially liquefied, and if gaseous, then it has to be evaporated.

Gases in Catalyser.

Nitrogen and hydrogen gases are passed repeatedly over the catalyser material and expensive temperature exchangers are required.

Purification of Gases.

An expensive gas purifying plant is required to remove the carbon monoxide, etc.

Size of Catalyst Bomb.

For an output of 20 tons of ammonia per day there is one bomb 3½ ft. dia. and 42ft. 8 in. high, weighing 74½ tons.

and 1,000 kw. to compress the gases to 200 atmospheres and circulate them at that pressure. The rest would be used in the motors for auxiliaries.

Such a plant using 10,000 kw. of electricity would produce by the Haber process about 5,000 tons of fixed nitrogen per annum and 33,000 cub. ft. of free oxygen per hour as a bye-product.

In the United States there are a number of concerns producing hydrogen as a bye-product from various electrolytic operations. In some individual cases it is enough to produce two or three tons of ammonia per day, and before long several of them will be producing.

Dr. F. G. Cottrell, Director of the Government Fixed Nitrogen Research Laboratory, Washington, D.C., writes me as follows:—

The actual production would not be specially significant and would all be sold as liquid and hydrous ammonia, for which there is a good and high priced market. It will serve to disseminate knowledge on the subject of ammonia synthesis, gradually train a technical personnel, and give opportunity for experiment and development on a practical scale.

COMPARISONS.

Processes are always more or less in a state of flux, and in making comparisons all that one can say is, that such and such a process appears to have advantages over another in the present state of the art. I think the following may be considered to be a fair summary of the two processes of making synthetic ammonia at the present time:—

CLAUDE.

A single operation at 900 atmospheres and one compressor.

The ammonia is condensed straight away in the liquid form, and if gaseous ammonia is required it can pass directly into this state.

Gases pass in succession through several bombs, and between each pass there are worms to remove the liquid ammonia.

A single protector tube containing spent catalyser material, removes the carbon monoxide.

For a similar output of 20 tons, 16 bombs are required, each 9in. dia. and 7ft. high, their total weight being under 12 tons.

Danger of Explosion.

Very considerable because of great size of bomb and large amount of contained gases.

The stresses are less in a number of small tubes and volume of contained gases is only 1/15.

Renewal of Catalyser Material.

A long and difficult operation requiring very skilled men. A very large quantity is required.

Very easy, as the material is carried by a steel head having an interrupted thread like a breech mechanism.

Heat of Catalyser.

The relatively small amount of heat given off at 200 atmospheres makes it necessary to employ one very large catalyst bomb.

The large disengagement of heat of reaction at 900 atmospheres enables the required temperature of 500° C. to be easily maintained.

Time of Starting.

Three whole days are required to heat the system and get started up.

The plant can begin to produce ammonia within five hours.

Size of Unit.

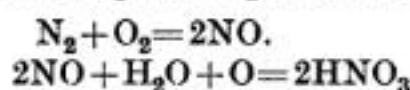
About 20 tons per day is minimum size of unit which is commercially feasible.

The unit size of plant can be as low as 2 tons of liquid ammonia per day.

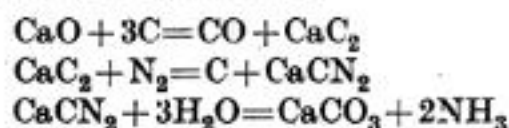
CHEMICAL EQUATIONS.

For those who are familiar with chemical equations a comparison of the processes can be written thus:—

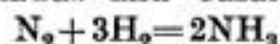
- (a) Synthesis of nitric acid by electric air and explosion processes.



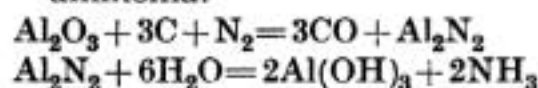
- (b) Manufacture of calcium, carbide cyanamid, and ammonia.



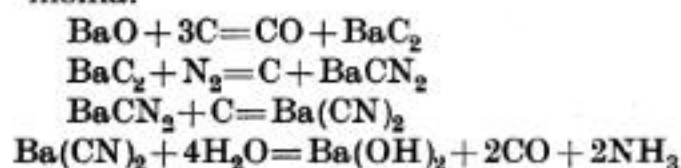
- (c) Synthesis of ammonia of Haber and Claude and Casale processes.



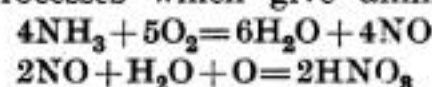
- (d) Manufacture of aluminium nitride and ammonia.



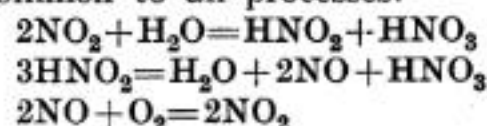
- (e) Manufacture of barium carbide and cyanamid and cyanide and then ammonia.



- (f) Conversion of ammonia to nitric acid by catalyser. This is common to all processes which give ammonia.



- (g) Absorption of oxides of nitrogen by water to give nitric acid. This is also common to all processes.



HABER V. CLAUDE PLANT IN FRANCE.

The annual consumption of nitrogenous fertiliser in France is about 110,000 tons of fixed nitrogen, and the home production is less than one-fifth of that amount. After the war the French Government decided to subsidise a company to build a synthetic ammonia plant at Toulouse to produce about 36,000 tons of fixed nitrogen per annum.

The company's bonds and dividends were to be guaranteed by the Government, and an agreement was entered into between the French Government and the Badische Anilin und Soda Fabrik, by which the company was to sell its rights and technical information and give assistance.

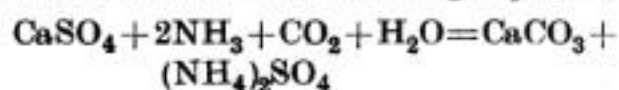
One million francs has been paid on account, but in view of the success of the Claude process the question has arisen whether it is wise to build a Haber-Bosch plant. Some politicians naturally favour a process invented by their own countryman.

The Senate referred the matter to a Committee, who recommended a Commission made up of members conversant with the technical details. Latest reports seem to indicate that the Haber-Bosch plant will not be built at Toulouse.

FERTILISERS FROM AMMONIA.

During the war Germany could not get sufficient supplies of pyrites with which to make sulphuric acid, and, therefore, experts of the Badische Anilin und Soda Fabrik developed a method of making ammonia sulphate from gypsum, which is a mineral form of calcium sulphate $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$.

It was found that when finely powdered calcined gypsum suspended in a solution of ammonia obtained from the Haber Bosch plant was acted on by carbon dioxide, the calcium carbonate precipitated and a solution of ammonia sulphate formed in accordance with the following equation:—



The carbon dioxide is a by-product of the manufacture of hydrogen from water gas. The solution of ammonia sulphate is filtered and evaporated in vacuum apparatus.

This process is used at the Leuna factory near Merseburg, Saxony, where such enormous quantities of ammonium sulphate can be turned out as completely to control the central European market.

Ammonia sulphate is much used as a fertiliser and especially for such crops as rice. It usually sells at a lower price per unit of contained nitrogen than any other fertiliser. Those who wish to study the question I would refer to papers by Dr. E. J. Russell,* Director of the Rothamsted Experimental station.

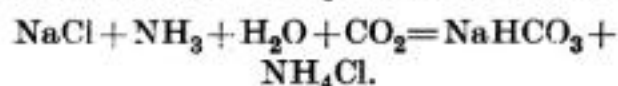
AMMONIA CHLORIDE.

Ammonium chloride is one of the coming fertilisers because it can be made cheaply, along with bicarbonate of soda by the Solvay Ammonia Soda process. This will probably be the method of using some of the ammonia made at the Bellingham-on-Tees plant.

The strength of usual salt solution of natural Cheshire brine is rather less than saturated, and under that condition only sodium bicarbonate is precipitated, the ammonium chloride with one-third of the original salt remaining in solution. From this solution, obtained by filtration of the

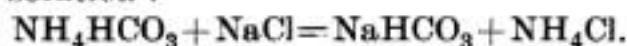
carbonated brine, the salt and ammonium chloride can be separated by crystallisation.

M. G. Claude uses brine which contains about 36 parts of salt per 100 parts of water at the ordinary temperature. It is saturated with ammonia gas and then carbon dioxide (recovered when making hydrogen) is passed into the ammoniacal brine under pressure. Decomposition takes place and ammonia chloride, NH_4Cl , and sodium bicarbonate, NaHCO_3 , are formed thus:—



The reaction is reversible, and a state of equilibrium is reached when about two-thirds of the salt are decomposed. Sodium bicarbonate is sparingly soluble in water, and even less so in a solution of common salt, and it is therefore precipitated in the form of a white powder. The operation is carried out in towers provided with cooling pipes through which cold water circulates.

Another modification, due to Schreib, is to saturate the filtrate from a bicarbonate with common salt, adding a further quantity of ammonia and again treating with carbon dioxide, when ammonium carbonate $(\text{NH}_4)_2\text{CO}_3$ is formed. By further addition of carbon dioxide, ammonium bicarbonate is formed, which precipitates sodium bicarbonate, and leaves ammonium chloride in solution:



By the addition of more salt and ammonia, the cycle of operations is begun again or the same solution may be used indefinitely. It is necessary to add solid salt to bring the solution up to strength.

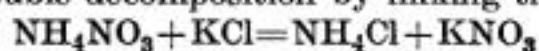
HIGH NITROGEN FERTILISERS.

There is also a considerable future for double fertiliser salts, which contain nitrogen and phosphorus or potash. In Germany a double salt of ammonia nitrate and ammonium sulphate, which is used for fertiliser purposes, has the composition:



It is prepared by crystallization and is less hygroscopic than the ammonium nitrate from which it is made. Its agricultural value is said to be excellent.

Another double salt is ammonium chloride and potassium nitrate, obtained by double decomposition by mixing thus:

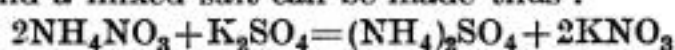


It is valuable because it contains the two plant foods, nitrogen and potash, and is

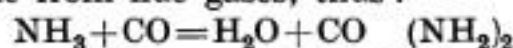
* See "Artificial Fertilisers: Their Present Use and Future Prospects," *Journal of the Society of Chemical Industry*, March 15th, 1917. Vol. XXXVI., pp. 250-261.

non-hygroscopic enough for fertiliser purposes.

For some crops it is better to have ammonia sulphate instead of ammonia chloride and a mixed salt can be made thus :



The Badische Anilin und Soda Fabrik make it by treating ammonium with carbon dioxide from flue gases, thus :—



Urea will be one of the best fertilisers when it can be produced chemically at a cheap enough price per unit of contained nitrogen. It contains 47 per cent. and the crystals are long needles and not deliquescent.

OXIDATION OF AMMONIA.

Another way in which ammonia may be used is to change it into a nitrate and thus into a quicker acting fertiliser. This is done by oxidation in the way first discovered in 1830 by Kuhlman. He noticed that when a mixture of an ammonia was passed over heated platinum sponge, red fumes of nitrogen oxides were given off.

Prof. Oswald, of Germany, developed a commercial process, and secured patents in every important country except his own, the reason of rejection there, being the previous work done by Kuhlman and others.

The Ostwald converter consisted of a vertical tube of nickel placed within a tube of enamelled iron, in which the air ammonia mixture passed at the bottom. The catalyst was a roll of platinum foil about 2 c/m wide coiled up in the mouth of the nickel tube. The hot gases pre-heated the incoming air ammonia mixture outside.

A type developed during the war consists of a water cooler aluminium box with baffles for distributing the incoming mixture of air and ammonia. It is surmounted by a conical hood of aluminium, which has a mica window.*

The catalyst consists of a layer of platinum gauze made of 0.065 m/m diameter wire woven to give 80 meshes to the inch. It is fitted with silver leads for electrical heating and fixed in an aluminium frame between the base and the hood.

* See "Oxidation of Ammonia," by C. S. Imison, B.A., and W. Russell, B.Sc., *Journal of the Society of Chemical Industry*, February 26th, 1922. Vol. XLI., No. 4, pp. 37T-45T. Also a paper by W. S. Landis read before the American Electro-Chemical Society, April 3rd, 1919.

Various small plants to oxidise ammonia were erected in England during the war, notably at Dagenham Dock, by Nitrogen Products and Carbide Company, and at Widnes by the United Alkali Company. The largest in the world was built at Mussels Shoals, Ala., and is described in Lecture II.

In normal times the process is handicapped by the fact that the price per unit of nitrogen is about the same, whether it is in the ammonia nitrogen form or the nitric nitrogen form. Therefore, commercially there can be no gain in making the change, for, of course, there is a loss in the conversion and the plant is expensive, especially the platinum catalyst.

It may be mentioned that the chief source of platinum is in the Ural mountains in Russia, and therefore any process which depends on this metal is considerably handicapped by uncertainty of supplies. It was a touch and go business during the war, when Russia collapsed. It would be unwise to depend on this rare metal in case of future trouble.

RESEARCH AND DEVELOPMENT.

Extensive researches into problems of nitrogen fixation were going on in Germany for many years before the war, and those of Professors Haber and Ostwald have been referred to. Several firms were also at work for many years before the war.

In 1913 the Badische Anilin und Soda Fabrik built a laboratory at the Oppau synthetic ammonia factory, 300ft. long by 100ft., and eight storeys high, which cost £150,000. During the war a staff of 215 experts was kept continuously at work and even after it was over, representatives of the Allies who visited the plant found 75 expert chemists and engineers still patiently at work.

In the United States a research on the Haber process was started in 1915 by the Bureau of soils, and it was continued by the Nitrate Division of the Ordnance Department after America came into the war. In 1919 a Fixed Nitrogen Research Laboratory was established at Washington, D.C., and it is now under the Department of Agriculture. The Director is Dr. F. G. Cottrell, and he has a staff of 115 assistants, and the annual budget is over £50,000.

Of course, in Norway a number of engineers and chemists are always busy, investigating modifications of the arc process, and the same may be said of Switzerland.

These countries are naturally concerned in utilisation of bulk water power.

In France, M. Georges Claude and his assistants, besides several other scientists, are always at work. Drs. Casale and Pfauser and Mr. C. Rossi also help to keep Italy well to the fore in nitrogen fixation.

Japan, which has been referred to already as having adopted the Claude process, is always on the *qui vive* for new improvements. So much is that the case that Japan may be almost taken as a barometer of scientific and engineering advancement. If the Japanese Government or the Mitsui Company takes up anything it can be safely assumed to be the latest and the best.

RESEARCH IN GREAT BRITAIN.

And now let us see what we have done and are doing. The arc process of fixing atmospheric nitrogen was the outcome of the philosophic research work of Priestley and Cavendish, followed by the more utilitarian investigations of Rayleigh, but practically all the development work has been done abroad, largely in Norway, Austria and France.

Various researches of Davy, Faraday, Perkin, Ramsay and Young, etc., resulted in the establishment of industries in Germany, more or less connected with fixation of nitrogen.

Preceding the war Dr. E. B. Maxted and myself were about the only ones doing any research in nitrogen fixation in this country. Some of us saw war looming ahead and knew the danger of relying on overseas supplies of Chili nitrate for explosives and the costliness and wastefulness of treating it with sulphuric acid, also largely dependent on overseas supplies of pyrites.

Dr. Maxted's work was principally on the direct synthesis of ammonia, and previous to his papers little was known in this country of the actual yields in the presence of promoted iron catalysts, which are the catalysts actually used for the synthesis of ammonia.*

After war did break out practically nothing was done for the first two years, and even then it only took the form of a research at University College, London. Eventually in May, 1918, it was decided that the Explosives Supply Department

should build a plant and regarding this Drs. Partington, M.B.E., and L. H. Parker, M.A., make the following comments in their book,* "The Nitrogen Industry."

The plans of the National Factory were to be drawn up by Mr. K. B. Quinan, the technical adviser to Lord Moulton. Mr. Quinan had, unfortunately, no theoretical or practical knowledge of the fixation of nitrogen, and for other reasons nothing had been done at the time of the Armistice beyond the acquisition of the site at Bellingham-on-Tees admirably exposed to Zeppelin attack.

After the war the apparatus at University College was dismantled, which was nothing more or less than sabotage. So far as general research of the nitrogen problem in this country is concerned, we are thus in the same position as before the war. A few are working privately in pigeonholes, as it were, and there is a complete lack of helpful co-operation.

I think this country should have a a nitrogen research department something like that at Washington, D.C. Failing that, I think there might be an institution where researches could be carried on by a scheme of Fellowships as is done at the Mellon Institute, Pittsburg.

EMPIRE DEVELOPMENTS.

Nitrogen fixation is as much an Empire matter as building new fighting ships and dockyards in which to berth them at strategic points. It is as much an Empire matter as having periodical conferences to discuss emigration problems and finance. It is as much an Empire matter as encouraging the cultivation of rubber or cotton or wheat in various parts of the Empire. All these supplies and all food supplies depend ultimately on cheap fixed nitrogen.

I know that our people in the Dominions expect the old country to keep in the van of engineering and chemical progress, not necessarily in having large plants, for mere bigness does not matter, but in initiating new processes and keeping them up to date.

During the last century, particularly about the earlier part of the Victorian era, we led the world in engineering achievement and in developing new scientific ideas. To-day it is different for a study of the moving engineering and chemical products will show that in a surprisingly large number of cases the pioneer researches done in this

* See "Ammonia Synthesis Catalysts and Plant," *Chemical Age*, 1919, Vol. I., p. 515.

† *The Nitrogen Industry*, published by Constable & Co., in 1922.

country have received their actual final development abroad.

It is our business to develop all the resources of the Empire, and there is much to be done. There are great natural water powers running to waste equal to anything in Norway, Switzerland or America; there is power of existing irrigation dams and of others that are contemplated. There are coalfields where fuel can be mined at a fraction of what it costs in Great Britain. There are great stretches of territory which need agriculturalists who know the chemistry of fertilisers and understand intensive cultivation by irrigation. We have the greatest potential granaries of the world.

We ought to be getting ready for these developments by having plants in this country in which the personnel can be trained, where new ideas can be given a fair trial and where improvements can be made to various processes. Other countries with less at stake are doing this, so why not Great Britain?

In conclusion, I think I cannot do better than quote the following, from a paper read recently by Mr. W. Wilson, M.Sc. :—

Electrical engineering generally has been founded chiefly on the brilliant work of great British electricians, such as Faraday, Maxwell, Kelvin, Hopkinson and Thompson, yet much of the work of application and development has been carried out in America and on the Continent, while quite a considerable proportion of the apparatus actually manufactured in this country during recent years has been made to designs supplied from abroad.

We have grown accustomed to abandoning our enterprises just where they begin to be profitable. By permitting foreign nations to act before us in this manner we are conceding them the initiative, *an error in tactics as serious in commerce as in war*. In the Colonial and foreign fields the effect of this loss of initiative is especially evident, for prestige is there an important factor in determining success.*

* See "Industrial Research with special reference to Electrical Engineering Development," read in October, 1923, before Institution of Electrical Engineers.

NOTES ON BOOKS.

ARCHITECTURAL EDUCATION A CENTURY AGO.
By Arthur T. Bolton, F.S.A., F.R.I.B.A.
London: Sir John Soane Museum. 1s.

This pamphlet, which forms number 12 of the publications of the Sir John Soane Museum, gives an account of the pupils and assistants of Sir John Soane, with special reference to the career

of his most distinguished pupil, George Basevi (died 1845), architect of the well-known Fitzwilliam Museum at Cambridge. The method of the education of the architects of the time is fully explained and the illustrations, from original pencil drawings made in Italy and Greece by Basevi in 1817-19, are fine examples of draughtsmanship. Particulars of the lives and works of some fifty-five members of the office of Sir John Soane are given, making a valuable record of the transitional period during and after the great war of the French Revolution.

DESIGNS FOR ARTISTIC LEATHER WORK. Elementary Part I. By Ellin Carter. London: E. & F. N. Spon, Ltd. 2s. 6d. net.

About two years ago a note appeared in these columns of Mr. Carter's "Designs for Artistic Leather Work." In response to enquiries from teachers for more simple designs suitable for beginners and children, he has now compiled this booklet, which contains twelve pages of easy subjects, intended to train the pupil in curves, careful and exact treatment of forms, such as stems of plants, the overlapping of lines, etc., and also for more advanced study a grouping of massed leaves and flowers, and berries and leaves, thus giving scope for gradation of work. The subjects seem to be well adapted for this purpose, and should prepare the young student to proceed to the author's more advanced text book.

NON-INTOXICANTS. Edited by Carl A. Nowak. St. Louis, Mo. C. A. Nowak, Publisher, Chemical Building.

NEW FIELDS FOR BREWERS. Edited by Carl A. Nowak, St. Louis, Mo. C. A. Nowak, Publisher, 2027, Railway Exchange.

New Fields for Brewers comprises 300 pages in which are detailed numerous schemes and suggestions for making use of the establishments, plant and staffs of the brewers during times of "National Prohibition"; the suggestions are widely various, and as examples we may mention malt flour, extracts, and diastase pastes; dried fruits, syrups and aerated beverages; while on p. 288 one may find nearly half a page of small type devoted to a scheme for preparing food from wood.

Non-Intoxicants seems to be the companion volume which is half promised on p. 13 of *New Fields for Brewers*; and this later volume deals so thoroughly with the leading aspect, *i.e.* "Soft Drinks," to use an American term, as to make it a quite comprehensive text book on non-alcoholic drinks.

The two works are well worth preservation on this side of the Atlantic for occasional reference or study; one notable point of interest being the light cast upon what may be regarded rather as sophistication of dietetic materials than adulteration. As an example of this, we may refer to the use of chemical preservatives in non-intoxicant